# POWER FOR THE DISMOUNTED SOLDIER

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## Introduction

The dismounted soldier needs a power source that is safe, small enough not to interfere with the soldier's actions, light enough to be a manageable burden, affordable, and reliable. It must provide sufficient energy for the soldier's needs and not become a liability because of thermal, acoustic, or other signatures.

This article outlines basic issues relative to soldier power and tries to assess how well a number of technologies under consideration by the power community might contribute to providing soldiers with the power needed. To provide a useful basis for considering soldier power sources, researchers assume the average power required by soldiers is 20 watts. Scaling the systems described up or down by a factor of two or so is not likely to present major difficulties. The 20-watt estimate for power is somewhat lower than power requirements used in a Land Warrior demonstration held in 2000 and somewhat higher than projected values for later versions of Land Warrior.

Power generation is the conversion of some stored form of energy, the fuel, to the desired form of energy (typically electrical power). At the most basic level, the choices of the starting form of the energy are chemical (fuels or batteries), radiant (solar or beamed energy), or nuclear.

## Solar Energy

Solar energy is rather diffuse, so the solar collector must be inconveniently large to collect sufficient solar energy to power a soldier. To collect the 240 watt-hours required for a day's energy, a 10-percent-efficient (typical of current flexible photovoltaic collectors) solar collector (spread out in bright sunlight for 6 hours) must be about 0.4 $m^2$ or about 16 by 40 inches. The collector must be kept nearly perpendicular to the sun's incoming rays; therefore, the soldier would have some difficulty maneuvering and keeping a low visual profile. Other forms of beamed energy have comparable difficulties.

## Nuclear Energy

Nuclear energy is noteworthy because it can be stored at energy densities more than 1,000 times greater than that of chemical fuels such as diesel fuel. However, society's concerns with scattering nuclear material over a battlefield make use of nuclear power sources very unpopular. Technically, a large problem with nuclear sources is that they tend to operate continuously regardless of whether the power generated is needed. Therefore, nuclear sources of high power tend to have short shelf lives, and sources of acceptable shelf life cannot be tuned to deliver high power. Despite these shortcomings, the very high energy density of nuclear sources suggests that some resources should be spent tracking developments that might make them more useful to the military.

## Chemical Sources

The most practical sources of energy for the soldier are chemical sources. These typically belong in one of two classes: fuels that react with oxygen from the air, and electrochemical batteries that contain all of the reactants within the battery. These fuels may react with oxygen to produce electricity directly (as in fuel cells); may be burned to generate heat for engines, thermoelectrics, or similar systems; or may be processed to other types of fuels (hydrogen) before being used to generate power. One advantage of these liquid fuels is the relatively high energy density—hydrocarbon fuels produce about 10 kilowatt-hours of energy per kilogram of fuel when reacted with oxygen from the air. A significant disadvantage, however, is the requirement for air. A battery can produce only 1 to 2 percent as much energy as an equal weight of fuel. However, batteries are self-contained and the energy produced is electricity, thus the typically inefficient steps of converting the energy of the fuel/oxygen reaction to electricity can be avoided.

## Batteries

The most common portable power sources are batteries. Modern primary (disposable) batteries can provide roughly 300 watt-hours per kilogram of battery weight. Secondary (rechargeable) batteries generally store about one-half the energy of an equal size primary. Furthermore, secondary batteries are not 100-percent efficient. Therefore, more than 120 watt-hours of charging energy may be required to get 100 watt-hours out of the rechargeable battery.

Batteries are the power sources of choice when the mission energy requirement is small enough that a reasonably light load of rechargeable batteries can supply the mission. At somewhat higher energy requirements, primary batteries are excellent technical choices, but are often very expensive solutions with costs in the range of $1,000 per kilowatt-hour. Although batteries are incrementally improved with each passing year, battery chemistry comes from a limited range of materials, and energy gains—while maintaining safety—are very difficult. Modern military batteries contain more than 200 watt-hours of energy compared with 260 watt-hours in a standard M61 hand grenade.

Rechargeable batteries can provide roughly one-half the energy of primary batteries on a weight basis. They provide a more economical power source when recharging is not too difficult or dangerous and are a useful source of energy for many training missions. However, recharging under battlefield conditions requires personnel to man the charging stations and transport relatively low-energy density batteries between the troops and the chargers. Models of the cost of operation seldom take all realistic variables into account.

## Fueled Systems

Fueled systems are of great interest because the energy of reaction of many fuels is large compared to the energy that can be stored in a battery. This difference is primarily because the heaviest reactant, oxygen, is taken from the air during use and does not have to be carried. This weight advantage must be traded against the serious disadvantage of using systems that need air to function. Fueled systems also tend to have some acoustic signatures and greater thermal signatures than batteries. To take advantage of the high energy density of the various fuels, the energy conversion device must be very light. (See accompanying chart for representative fuels and energy content.)

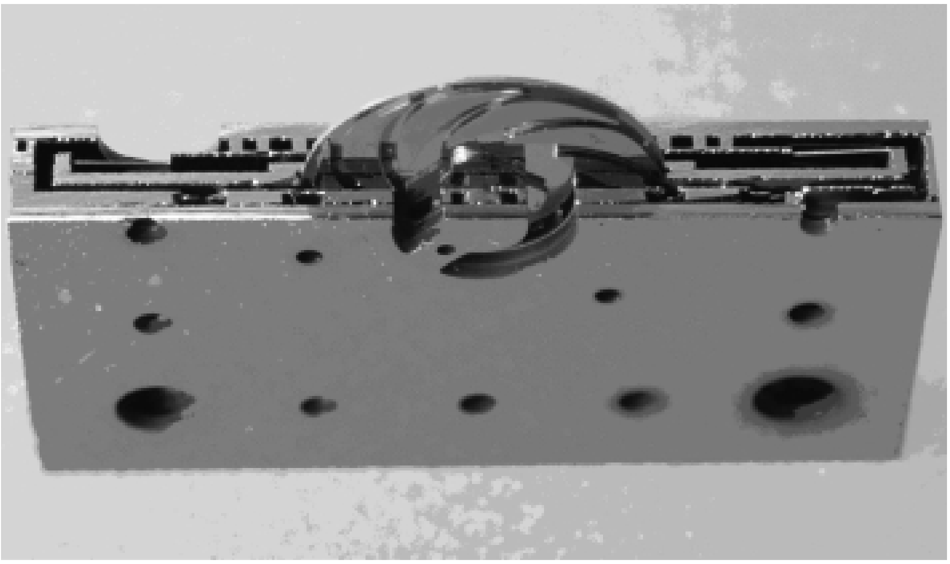
## Fuel Cells

Fuel cells have recently received a great deal of attention, both in the media and in the technical community. Fuel cells are devices that convert the energy of the fuel/oxygen reaction directly to electricity by channeling some of the electrons that move during chemical reactions through the electrical load before allowing them to move to the reaction products. The simplest fuel cells are hydrogen/air fuel cells (HAFCs), which have reached a high state of development because of their use in space missions during the last three decades.

### SPECIFIC ENERGY OF VARIOUS CHEMICAL SYSTEMS IN WATT-HOURS/KILOGRAM

| Source | Specific Energy (Theoretical) | Specific Energy (Practical) |
|---|---|---|
| Steel springs | 0.25 | 0.15 |
| Rechargeable batteries | | 35-200 |
| Primary battery—Li/$SO_2$ | 1,400 | 175 |
| Primary battery—Li/$SOCl_2$ | 1,400 | 300 |
| Zinc air | | 300-400 |
| TNT | 1,400 | N/A |
| Methanol* | 6,200 | 1,500-3,100 |
| Ammonia* | 8,900 | 1,000-4,000 |
| Diesel (JP-8 is similar*) | 13,200 | 1,320-5,000 |
| Hydrogen* | 33,000 | 1,000-17,000 |
| Nuclear | 2,800,000 | 190,000 |

*Data is for energy of combustion in air



*Cross section of a microturbine: The device is 3.7mm thick by 21mm long.*

The primary drawback to HAFCs is that they need hydrogen as the fuel. Although hydrogen is an excellent fuel in many respects and has a very high energy density on a weight basis, it is difficult to store. Even liquid hydrogen contains only about one-half as much hydrogen per liter as does a hydrocarbon fuel such as diesel fuel. Hydrogen must be kept extremely cold to remain liquid, and large quantities of liquid hydrogen are relatively less safe than fuels such as diesel fuel.

Processing (reforming) hydrocarbon fuels to produce hydrogen can be accomplished during a reasonable range of conditions, but sulfur and other materials that make up logistics fuels present a challenge that cannot be adequately handled today. Another form of fuel cells, solid oxide fuel cells (SOFCs), avoid some of the fuel processing difficulties by operating at a high temperature and being relatively tolerant of impurities in the fuel stream. One trade-off is a much slower startup time. SOFCs are much less a mature technology than HAFCs, and no good examples of soldier-size units exist.

One approach to minimizing fuel processing is to use direct oxidation fuel cells such as units that convert methanol to electricity, water, and carbon dioxide at modest temperatures of about 70 C. Current units are about twice as heavy and bulky as HAFCs, but the fuel supply, liquid methanol, is relatively compact.

## Other Sources

A fairly recent approach to small power sources, the microturbine, has gained considerable attention. These devices are very small turbo machines operating at more than 1 million revolutions per minute. Complete power systems have not yet been fabricated, and issues such as cost, longevity, and signature will remain open questions for several more years. The devices appear to be very lightweight energy converters, but the early units are not expected to be very efficient and will require a significant amount of fuel.

Another recent approach to soldier power is alkali thermal-to-electric conversion (AMTEC). This technology uses a heat source (a JP-8 fueled burner is one possible source) to ionize a small amount of sodium metal. The resulting ions and electrons can be used as a power source prior to recombining them at the lower temperature end of the device. These devices have demonstrated 18-percent thermal-to-electric conversion and are likely to provide overall efficiencies of fuel to electricity ranging from 15 to 20 percent. With innovative approaches to lowering the weight of the systems, the energy density may be a factor of 3 to 5 better than primary batteries when sized for a 72-hour mission.

## Conclusion

In addition to the power sources addressed in this article, a variety of other soldier-size power sources are being studied. It is likely that in the next 3 to 5 years, small hybrid-power sources that use a battery for startup, are air-independent, stealthy, and have a fueled system to keep the battery charged, will provide soldiers with more electrical energy per unit weight than current batteries. Fortunately, there is a sizable commercial market for similar sized power sources to provide the volume required to keep the units affordable.

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